

A THREE COLOR BILEVEL SCANNER

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ELECTRICAL MEASUREMENTS

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PROBLEMS IN IMAGE PROCESSING
DIGITIZATION OF IMAGES, BLOOD FLOW VISUALIZATION
AND A MODEL FOR ULTRASOUND SCATTERING

AKADEMISK AVHANDLING

som för avläggande av teknisk doktorsexamen vid
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av

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civ ing, Ssk

Digital bildbehandling och datorgrafik är två områden inom datatekniken som vuxit mycket snabbt. Möjligheten att med hjälp av bilder förmedla stora informationsmängder är väl anpassad till människans möjlighet att snabbt tillgodogöra sig stora mängder data. I takt med billigare och snabbare datorer och förbättrade möjligheter att i svart/vitt såväl som färg registrera och presentera bildinformation har antalet användningsområden stadigt ökat. Digital bildbehandling och datorgrafik är numera vanliga hjälpmedel inom bl a medicin, där ultraljudsbilderna och dator-tomografin kanske utgör de främsta exemplen; - geologi och geovetenskap, för att bl a utvärdera och presentera mätdata vid letning efter naturresurser; samt rymdteknik för att förbättra och presentera satellitdata. På senare tid har också användandet av kartor som beskriver den geografiska fördelningen av statistiska data (ex miljöföroreningar, befolkningstäthet, trafiktäthet) blivit ett viktigt hjälpmedel i samhällsplaneringen.

Den föreliggande avhandlingen behandlar olika delområden av det stora gebitet bildbehandling med hjälp av datorer. Avhandlingen omfattar sex rapporter enligt följande:

- I. A three color bilevel scanner. Report 4/1981, Department of Electrical Measurements, Lund Institute of Technology, Lund, Sweden.
- II. A color separating optical scanner head. Report 2/1981, Department of Electrical Measurements, Lund Institute of Technology, Lund, Sweden.
- III. The conversion of a continuous-tone image into a bilevel representation - applied to a color image scanner and a color ink jet plotter. Report 3/1981, Department of Electrical Measurements, Lund Institute of Technology, Lund, Sweden.
- IV. A color raster graphic system for geoscience applications. Report 5/1981, Department of Electrical Measurements and Lund University Computing Centre, Lund University, Lund, Sweden.
- V. Topographic display and quantitative analysis of blood flow marker distribution in normal and infarcted hearts. Report DURL 81-1, Diagnostic Ultrasound Research Laboratory, University of Rochester, Rochester, N.Y., USA.
- VI. Characterization of volume scattering wavenumber power spectra in isotropic media from wavenumber power spectra of scattering by planes. Report DURL 81-2, Diagnostic Ultrasound Research Laboratory, University of Rochester, Rochester, N.Y., USA.

Arbete V har lämnats in för publicering i IEEE Transactions on Biomedical Engineering. Arbete VI har delvis blivit presenterat på 9th International Symposium on Acoustical Imaging, 3-6 dec, 1979, Houston, Texas. Vidare har arbetet lämnats in för publicering i The Journal of the Acoustical Society of America.

Ett problem vid digitalisering av färgbilder är de stora datamängder som fordras för att lagra bildinformationen. Om exempelvis en färgbild delas in i 3000 x 3000 diskreta bildpunkter där varje bildpunkt färgsepareras i tre färgkanaler samtidigt som varje kanal digitaliseras med 8 bitars noggrannhet (= 256 gränivåer) uppstår ett lagringsbehov av 27 Mbyte.

Skall bilden endast användas för binär bildbehandling och sedan presenteras på en binär display eller hardcopy-enhet kan mängden data reduceras till 27 Mbit redan vid digitaliseringen.

Arbete I ger en översikt av de olika delarna i en speciellt konstruerad färgbildscanner, som utför en sådan reducering av datamängden, s k bildkompression. Scannern är utvecklad för att digitalisera och omvandla färgbilder eller kartor till ett binärt format som är direkt kompatibelt med en tidigare utvecklad färgbildsplotter (Bladh et al. 1979).

I arbete II ges en detaljerad beskrivning av det speciellt utvecklade optiska avsökningshuvud, som används i färgbildscannern. Avsökningshuvudet utnyttjar aperturerna på tre optiska fibrer, kombinerat med optiska färgsepareringsfilter för att färgseparera det reflekterade ljuset från bildelementen i originalbilden. Den mekaniska och elektriska uppbyggnaden beskrivs detaljerat. Dessutom redovisas mätningar och beräkningar av en del detektorparametrar. Slutligen ges ett par exempel på ytterligare signalbehandling.

Arbete III ger en detaljerad beskrivning och utvärdering av den s k ordered dither teknik (Judice et al. 1974), som används i färgbildscannern för att konvertera en kontinuerlig färgbild (t ex färgfotografi) till en binär färgrepresentation. Vidare visas möjligheten att i ordered dither tekniken införa justeringar för in- och ut-karakteristiken hos scanner respektive plotter, samt att införa kontrast- och luminanskontroll. I arbetet ingår också en kortfattad beskrivning av teorin för binära färgbilder. Slutligen ges några exempel på scannade färgbilder som plottats av färgbildsplottern.

Ett grafiskt bildbehandlingssystem främst inriktat på geovetenskapliga applikationer beskrivs i arbete IV. I arbetet ges en kort beskrivning av såväl hårdvara som mjukvara. Vidare ingår några applikationsexempel i färg, som beskriver några av de möjligheter som systemet erbjuder.

Ett viktigt användningsområde för digital bildbehandling har som nämnts uppstått i bearbetningen av olika typer av medicinska bilder. Två exempel på detta lämnas i arbetena V och VI.

I arbete V beskrivs hur man med hjälp av olika bildbehandlingsmetoder kan framhäva variationer i blodflödet i hjärtmuskulaturen (hund och svin) med och utan infarkt. Två olika typer av bilder används i arbetet: Fotografier av UV-fluorescensen från tunna skivor av hjärtmuskulaturen då blodet märkts med Thioflavin S, samt autoradiografier av tunna skivor hjärtmuskulatur då blodet märkts med ^{85}Sr -märkta mikrosfärer. Arbetet redovisar några olika metoder att presentera blodflödesvariationer. Slutligen görs en mera kvantitativ jämförelse av data från de två bildtyperna och en manuell isotop-registrering.

Ett relativt nytt användningsområde för ultraljudstekniken är vävnadsidentifiering. Målet med denna metod är att kunna identifiera olika typer av vävnader och förändringar i dessa, exempelvis infarkter och cancer. Problemen är emellertid många och mycket utvecklingsarbete krävs för att få ett fungerande system. Många metoder utnyttjar det faktum att ultraljudet till viss del sprids i olika riktningar när det utbreder sig i en vävnad. Spridningen beror på vävnadens struktur och på ultraljudets frekvens (Waag 1980).

I arbete VI beskrivs en bildbehandlingsmetod för att med hjälp av en serie digitaliserade bilder (inläst via optiskt mikroskop + TV-kamera), som representerar tvärsnitt ur en vävnad, få fram ett optiskt diffraktionsmönster som går att kvantitativt korrelera med det effektspektrum som beskriver ultraljudets spridning i vävnaden. Metoden förutsätter att vävnaden statistiskt sett består av sfäriska spridningscentra. Då förenklas nämligen de Fourier-transformrelationer som råder. I arbetet testas och utvärderas metoden på data från analytiska funktioner, experimentmodeller och levervävnad.

Avslutningsvis vill jag framföra mitt varma tack till:
Professor Hellmuth Hertz för den stimulerande uppmuntran jag fått under arbetets gång;
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alla anställda och kolleger på institutionen för elektrisk mätteknik, vars hjälp och stöd varit en förutsättning för denna avhandlings tillkomst. Speciellt gäller detta verkstadspersonalen med Lennart Nilsson i spetsen och institutionens sekreterare Margaret Jansson och Anita Borné.

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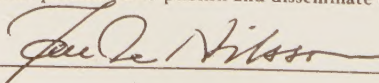
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Abstract The dissertation consists of six reports: I A THREE COLOR BILEVEL SCANNER. A design of a color image scanner that converts a continuous-tone color image into a bilevel color representation is presented. II A COLOR SEPARATING OPTICAL SCANNER HEAD. A new design of a color separating optical scanner head is described. III THE CONVERSION OF A CONTINUOUS-TONE IMAGE INTO A BILEVEL REPRESENTATION - APPLIED TO A COLOR IMAGE SCANNER AND A COLOR INK JET PLOTTER. The implementation and evaluation of a pseudo-gray scale algorithm in a color image scanner is presented. IV A COLOR RASTER GRAPHIC SYSTEM FOR GEOSCIENCE APPLICATIONS. The color raster graphic system of the Department of Electrical Measurements, Lund, is described, and a few applications in geoscience are given. V TOPOGRAPHIC DISPLAY AND QUANTITATIVE ANALYSIS OF BLOOD FLOW MARKER DISTRIBUTION IN NORMAL AND INFARCTED HEARTS. Computer-based image analysis methods have been developed for the study of blood flow marker distribution in ischemic and non-ischemic hearts. VI CHARACTERIZATION OF VOLUME SCATTERING WAVENUMBER POWER SPECTRA IN ISOTROPIC MEDIA FROM WAVENUMBER POWER SPECTRA OF SCATTERING BY PLANES. In an isotropic medium simplified one-dimensional Fourier-transform relations can be used to determine the wavenumber power spectrum of scattering by a volume from power spectrum of scattering by a plane within the volume.			
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A THREE-COLOR BILEVEL SCANNER

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ABSTRACT

The design of a color image scanner is presented. The scanner converts a continuous-tone color image into a bilevel color representation that can be plotted directly on a three-color ink jet plotter.

After a short introduction and a description of the color jet plotter, the report centers on the color scanner system. The threshold technique used to convert the continuous-tone image into a bilevel representation is described as well as its hardware implementation. Finally, a few results and applications of the scanner - color plotter system are given.

INTRODUCTION

Compared to alphanumeric text, pictorial information has the advantage that it can present complicated relations in a more compressed and still easily understandable way. Due to the excellent color perception of the human eye this advantage is further enhanced if color is used. This has lead to the growth of computer output devices generating graphs and pictures, mostly in black and white. These output devices are of two types, vector oriented and raster oriented. For picture generation the raster oriented output devices are most commonly used, and this is especially true for color displays.

The recent change from black and white to color graphics using color displays generated the need for hard copy output devices in color. Ordinary ribbon dot-matrix printers can generate raster pictures in black and white but usually not in color. Instead the Dunn Camera, Xerox color printer and ink-on-demand color output devices have been used.

The problem of generating color hard copies was realized at our department already in 1970 when Smeds (1972) started to develop a plotter using electrically controlled ink jets in three different colors for a hardcopy color output device for computers. This plotter has been in operation at the Computer Center of the University of Lund (LDC) since November 1972. In 1974 a 615 x 665 mm² drum plotter was developed (Bladh et al. 1979 and 1980). Today, a similar drum plotter based on the above mentioned plotter is commercially available through Applicon Inc., Mass., U.S.A.

Since 1972 these plotters have proved useful in several different applications such as presentation of geological and seismic exploration data, integrated circuit layout designs, maps for government and community planning, business graphics, art work and different statistical data presentations. An important reason for the usefulness of these plotters is the graphic Fortran software package COLOR developed at LDC. It enables users with little programming experience to convert

their input data into complicated but easily understandable pictures (Jern 1978).

In many of the above applications the input data alone is not sufficient to generate a useful output image. For example, a colored pictorial representation of the population density in different parts of Sweden will be difficult to interpret if a map over Sweden is not included as a background in the picture. Today, this background information, or base map, is generated manually using a point-to-point digitizing equipment. This step in picture generation is very time consuming and hence costly. Therefore, the potential of the color plotters for e.g. community planning has not been used to its full extent as the preparation of the base maps is too expensive.

To overcome this bottleneck a color scanner was developed which automatically digitizes colored pictures and maps and transforms them into a bilevel representation compatible with the color jet plotter. Since the design of the scanner in some aspects had to conform with the Color Jet Plotter design the properties of this plotter will be described first.

THE COLOR JET PLOTTER

The color jet plotter is a drum plotter. As shown in Figure 1, three ink jets with the colors magenta, yellow, and cyan, mounted on a common carriage are slowly moved by a screw-drive parallel to the surface of a drum rotating with a constant surface speed of 5 m/sec. The exact position of the jets relative to the drum surface is known at each moment as the screwdrive is activated by a stepper motor and the drum rotation is monitored by a shaft encoder. For each revolution of the drum the carriage carrying the three ink jets is moved sideways 0.2 mm, generating a recording line density of 5 lines/mm. The same resolution is maintained along the recording line through the shaft encoder. The ink pumps, not shown in the Figure, are supplying a constant flow of ink during plotting. To allow on/off modulation of the ink jets, a special electrode system was designed (Hertz et al. 1974). It accepts

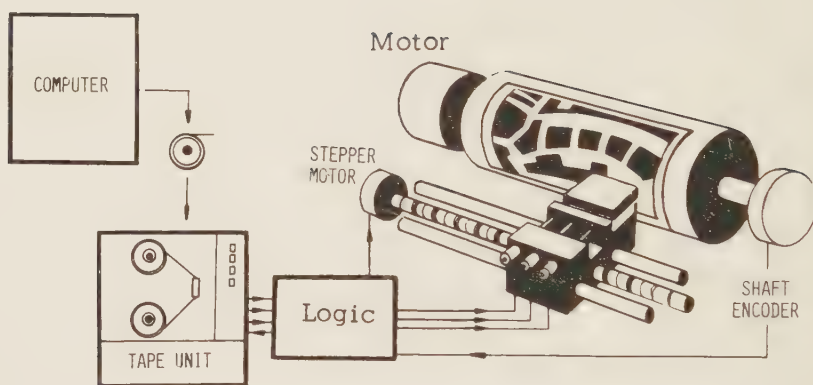


Figure 1. Basic units of the colorjet plotter. The information to be plotted is computed in a suitable format by a computer and stored on a magnetic tape. This tape is then read by a magnetic tape unit into a buffer memory. The read-in and read-out periods of the memory are governed by control circuits, and the read-out signals are used to modulate the intensity of the three ink jets (magenta, yellow, and cyan) mounted on a common carriage in front of the rotating drum carrying the recording paper.

on/off modulation frequencies in excess of 100 kHz. On/off modulation of the ink jets is effected by data from a magnetic tape station reading a tape.

Each picture element (pixel) in a plot is $0.2 \text{ mm} \times 0.2 \text{ mm}$ and plotted in 40 μs . A picture using the available $615 \times 665 \text{ mm}^2$ recording surface can contain $3075 \times 3325 > 10.2$ million ink dots in each color, altogether > 30.6 million bits of information. The plotting time for a picture this size is only about 10 minutes. All three colors are plotted simultaneously.

The three colors, magenta, yellow, and cyan, can be deposited on top of each other on the recording medium. This mixing creates other colors. Using the 3 colors only allows 8 possible combinations including white. However, in many instances a much larger range of color shades is required. To achieve this a matrix method is used. As the plotter only can handle bilevel information, the matrix method must be implemented in software on the host computer.

Often an $0.8 \times 0.8 \text{ mm}^2$ matrix consisting of 4×4 pixels of each primary color is used. By different combinations of filled and unfilled pixels within the three matrices, several thousand color shades can be generated. However, the human eye cannot perceive this many different color shades and, therefore, only a few hundred are used in the COLOR software supporting the plotter.

An example of a matrix method is shown in Figure 2. The example simulates the halftone method often used in conventional printing. The matrix is colored from its center towards the edge in a spiral depending on the darkness of the area in the original continuous-tone image. This simulated digital halftone gives the bilevel image a typical raster fashion.

As a major object of this work was to match the scanner to the plotter, the same scanning/plotting line density, pixel size, and image surface size were used. It was also desirable that the scanner directly con-

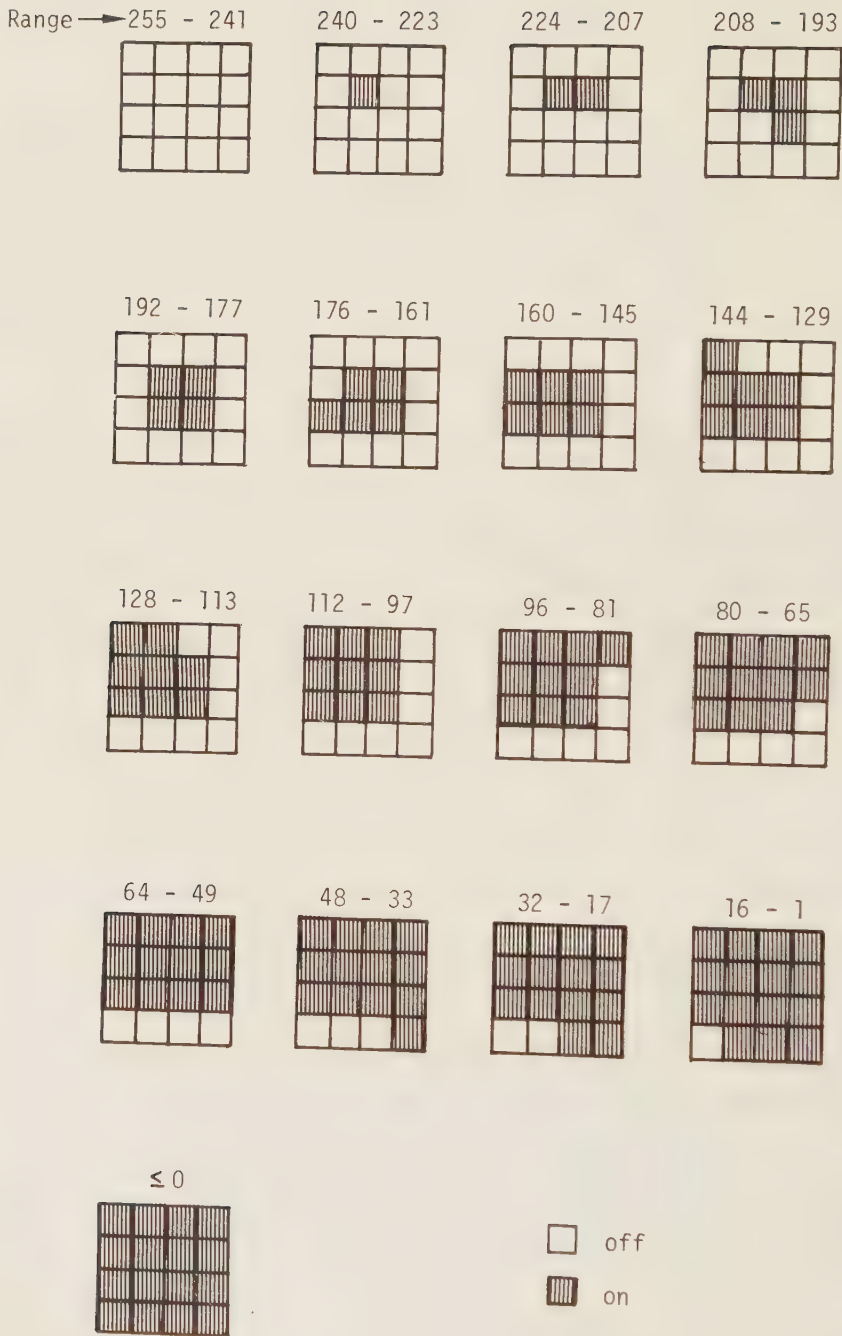


Figure 2. Uniform intensity digital halftone patterns using a 4 x 4 threshold matrix.

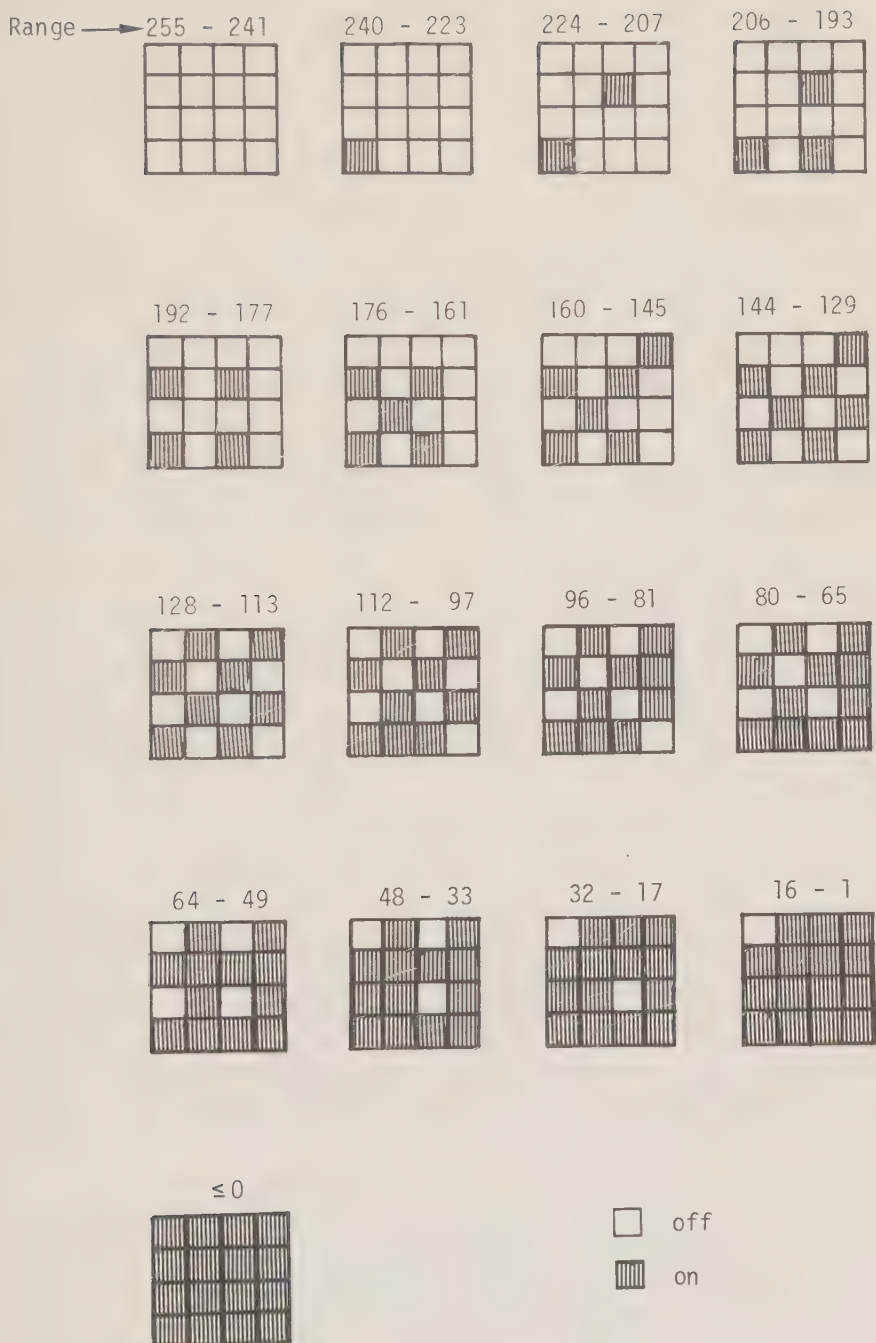


Figure 3. Uniform intensity ordered dither patterns using a 4 x 4 threshold matrix.

verted the continuous-tone images into bilevel representation using a matrix method. Thereby additional time-consuming computations in a host computer were avoided.

COLOR SCANNER

Mechanical configuration

To ensure compatibility with the color jet plotter in scanning surface size, the color scanner uses the same mechanical configuration as the color jet plotter (Bladh 1982) with the recording head replaced by an optical scanner head (cf. Figure 1). This eliminates the necessity of decreasing the size of maps or pictures to be scanned by a photographic process, as normally required for commercially available scanners. The scanning time for a color image is approximately 10 minutes.

Optical system and color separation

Color separation is usually costly to achieve. To reduce this cost and to allow great flexibility in the selection of filters, a new optical scanner head was developed (cf. Figure 4). The image to be scanned is illuminated by a slightly focused cold-mirror halogen incandescent lamp (Osram 64255 20W) not shown in the figure. The cold mirror reduces the IR-radiation reaching the image on the drum surface. The information from the image passes through a microscope objective (Zeiss 10x) through an additional lens and IR-glass filter into three optical fibres, 0.4 mm in diameter. The input ends of the glass fibres are positioned close to each other along a line parallel to the movement of the drum surface and their spacing corresponds to 0.2 mm on the drum surface. After passing through filters, the light is detected at the other end of the fibres by photodiodes (EE&G HUV 1000B). The diodes are spaced about 20 mm apart.

The optical resolution of the system is 0.1 mm. It is determined by the total magnification (4x) of the microscope objective and an additional lens as well as by the diameter of the optical fibre (0.4 mm) which serves as a diaphragm. As the color jet plotter uses a line density of 5 lines/mm, the optical resolution of the scanner is reduced to the same resolution by sampling in the electronic circuitry.

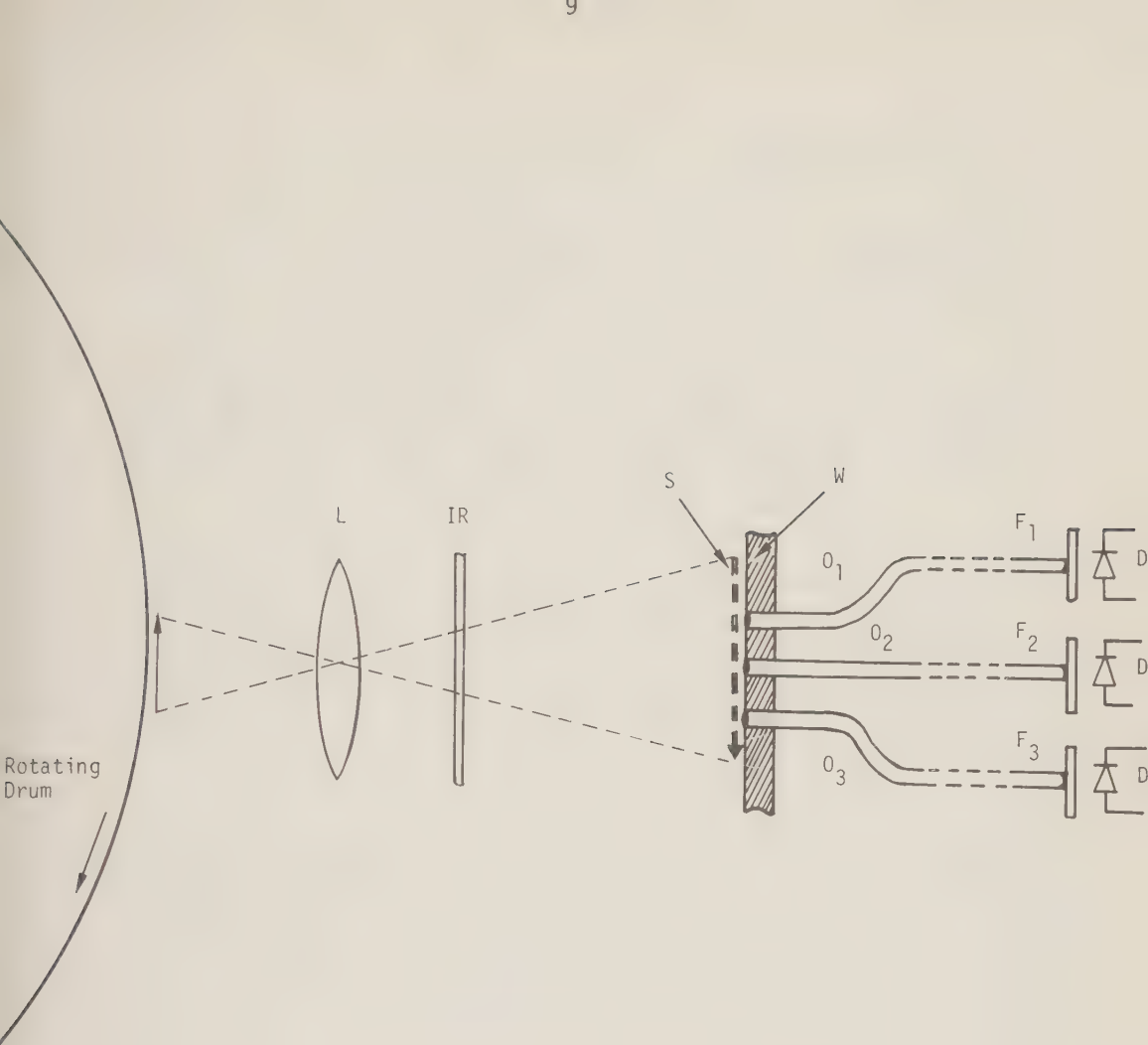


Figure 4. The lens L projects a small part of the image on the drum onto a surface S of wall W. In the wall three (or optional four) small holes are drilled close to each other along a line which is parallel to a scanning line (= parallel to the drum rotation). In each hole an optical fibre $O_1 - O_3$ is introduced which collects the light falling into its finely ground end and guides it through a color filter $F_1 - F_3$ onto the photodiodes $D_1 - D_3$. Color separation filters in front of the photodiodes $D_1 - D_3$ separate the pixel color into its tri-color contents.

SIGNAL PROCESSING CIRCUITS

Analog electronics

As already mentioned EE&G photodiodes HUV 1000B are used as light detectors because of their good sensitivity and S/N ratio in the entire visible spectral range. These detectors also include an integrated amplifier used as a transimpedance amplifier. In spite of that, the signal has to be amplified further about 50 times in external amplifiers before being applied to the A/D-converter (cf. Figure 6).

Further, some signal processing circuits are located in the analog section of the electronic circuitry. The signal is always low-pass filtered to decrease noise. Gray scale expansion and compression with or without gray scale offset is achieved by adjusting the amplification and DC-level. Also edge enhancement can be obtained in the image by the use of a differentiation circuit.

After this the signal is applied to an 8 bit A/D converter sampling the signal once for each 0.2 mm movement of the paper on the drum, i.e. once for each pixel. As the 8 bit A/D converter's conversion time, 4 μ s, is more than 10 times shorter than the time it takes for the drum surface to move 0.2 mm at full speed (40 μ s), no sample and hold amplifier is used.

Since the color jet plotter works in a bilevel mode only, and attains color shades by a matrix technique, the 8 bit digital signal from the A/D-converters cannot be used directly to control the ink jets in the plotter. Instead, the continuous-tone image has to be converted into a bilevel matrix image as will be explained in the following.

Dither technique

The reproduction of halftone colors with bilevel printers (offset printing, certain CRT displays, AC plasma displays, mechanical dot matrix printers and ink jets) can be attained in different ways, all of which use a matrix pattern, e.g. digital halftone, ordered dither, or other matrix methods (Gard 1976, Jarvis et al. 1976, Judice et al. 1974, Knowlton et al. 1972).

The ordered dither method creates color shades by successively filling the positions in a square matrix (cf. Figure 3) according to a special rule to reduce objectionable patterns in the picture and to obtain a good spatial resolution (Judice et al. 1974).

Because of the higher spatial resolution possible when using ordered dither compared to digital halftone, this method was mainly used in our application. The size of the matrices was normally 4×4 pixels or $0.8 \times 0.8 \text{ mm}^2$, but 8×8 pixel matrices were also used.

The conversion of the digital continuous-tone color signal into matrix form is attained with the help of a comparator and a threshold generator which essentially operate as a two-dimensional 4×4 position discriminator. Its function can be explained by comparison with a normal discriminator.

A simple discriminator is obtained by a Schmitt-trigger circuit, to which an analog signal is applied. If the analog voltage is below the DC voltage at the reference input of the Schmitt-trigger the output of the circuit is a logical 0, while a higher signal voltage produces a logical 1. By suitable setting of the reference voltage the threshold voltage of the Schmitt circuit can be determined at will. Thus a Schmitt-trigger can be used to transform an analog signal into a coarse digital signal.

Now, looking back at Figure 3, we see that the darkness of the color is increased by increasing the number of dither matrix positions covered by ink. For simplicity we assume in the following this color to be black. Further, let the amplitude of the signal from the optical scanning head be proportional to the lightness of the image area scanned. Hence, the smaller this amplitude the more black ink dots should be deposited in the matrices in the corresponding area of the reproduction.

Let the signal amplitude be 0 when the original is black (no light reflection) and $2^8 - 1 = 255$ if it is white. Then all 16 dither matrix

positions should be filled with black ink dots if the signal is 0. Vice versa, a signal of 255 should cause all the matrix positions to be free from ink. At intermediate signal values the number of matrix positions not covered with black ink should increase proportionally to the voltage of the signal following the dither patterns shown in Figure 3. This can be accomplished in the following way.

In the left upper edge of Figure 5 an original to be scanned is depicted. Due to the scanning format used, the original is divided into pixels of an area $0.2 \times 0.2 \text{ mm}^2$ as indicated in the figure below (PICTURE). Due to the construction of the drum scanner, these pixels will be scanned consecutively in the vertical direction beginning with the first scanning line at the left side of the picture. For the sake of the argument the reflectance measured by the optical scanner head when scanning the original is inscribed in each matrix position. Thus the encircled area indicated in Figure 5 has the same lightness in all pixel positions while the lightness changes at other parts of the image.

At the bottom of Figure 5 a repetitive 4×4 matrix pattern is shown. Each matrix is filled with the same fixed numbers between 0 and 255 which, in the ideal case, increase in a linear fashion. In the following this fixed 4×4 matrix is called the threshold matrix.

Now, to obtain a pseudo-gray scale in the bilevel reproduction each pixel is compared with its corresponding position in the fixed threshold matrix. If the signal value of the pixel is smaller than or equal to the number given in the threshold matrix, a logical 1 is saved in a corresponding position of a memory, e.g. a magnetic tape. When the image is reproduced later this causes an ink dot to be deposited at the corresponding pixel position of the reproduction. Vice versa, if the signal value is larger than the matrix number a logical 0 is saved. Therefore, the corresponding pixel position will receive no ink during the reproduction process.

The comparison described above is made pixel for pixel, thus converting

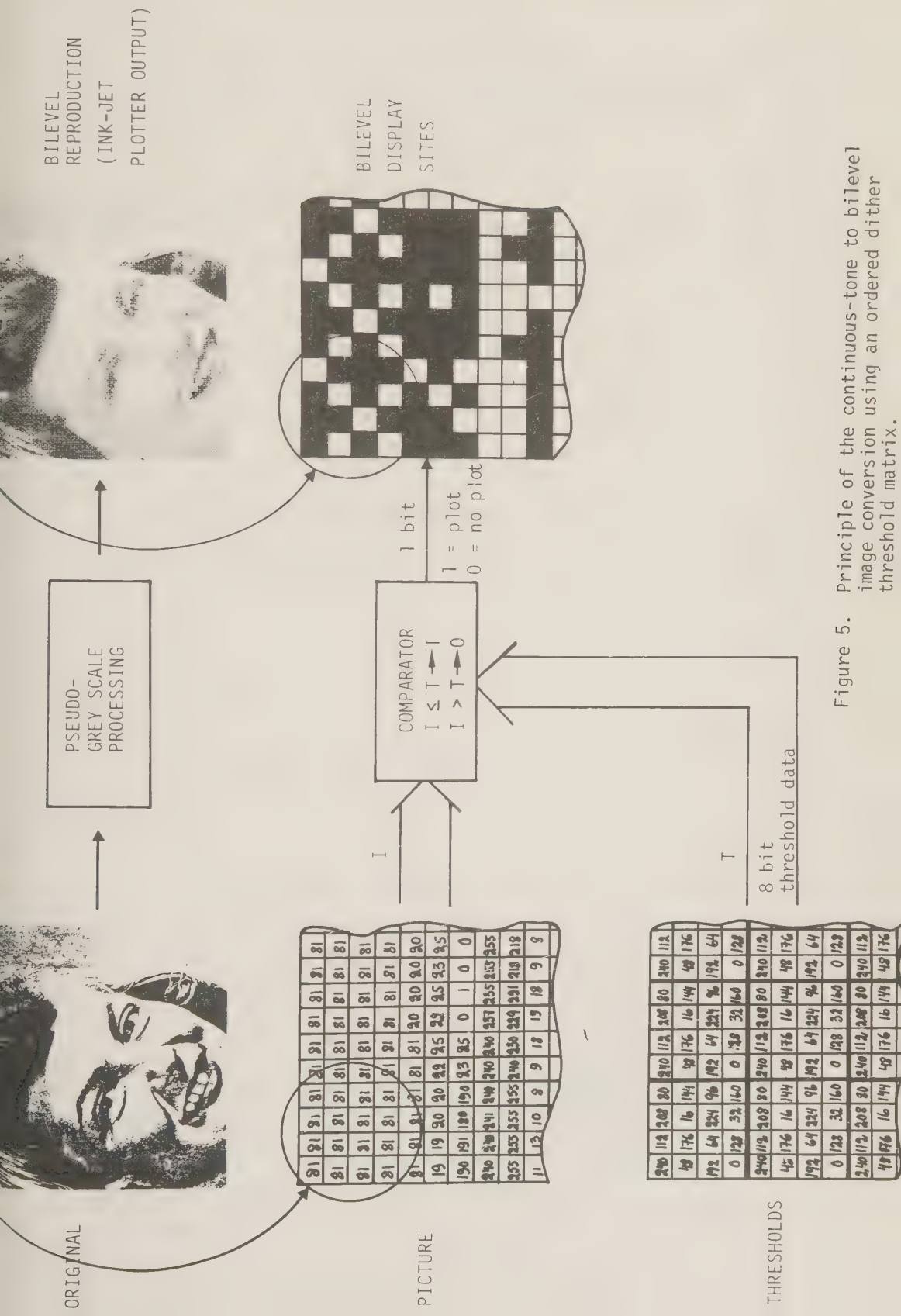


Figure 5. Principle of the continuous-tone to bilevel image conversion using an ordered dither threshold matrix.

a continuous-tone image into a pseudo-gray scale image using dither matrices. Since the original signal consisted of 8 bits for each pixel, a signal compression of 8 is obtained at the same time. Further, if the gray shade changes inside of a matrix as demonstrated in the area outside the circle of Figure 5, a corresponding change in the dither matrix is produced by the comparison process. Thus the resolution of the dither image is not limited by the size of the matrix used.

If images containing shades of different colors are to be reproduced by the bilevel dither method, a very similar procedure as that described above is used for each color. In that case the three threshold matrices are not linear as described above since the ink jets cause splatter outside the pixel area.

Actually these matrices are selected so that the best color reproduction is obtained which corresponds to an analog gamma correction normally used with video signals (Nilsson & Nygren 1981).

Digital electronics

The implementation of the dither technique can be realized in principally two different ways.

1. Software implementation

The 8-bit information from each color in each pixel is stored in a host computer system. Using suitable software the matrix image is later calculated by the computer. In our application with over 30.6 million pixels 29 Mbytes of disc storage is needed in this case.

2. Hardware implementation

The 8-bit information is processed in a hardware circuit to produce the matrix image immediately. This can be achieved by comparing the 8-bit color

signal, with a threshold from a predetermined matrix in a digital comparator, and only the bilevel information is stored.

While the software implementation requires too much storage and processing time for our applications, the drawback of the hardware implementation is the lack of flexibility in threshold matrix changes. Our implementation is therefore based on a microprocessor system using a hardware implementation with software control (cf. Figure 6).

To allow flexibility in the selection of thresholds, the threshold matrices are loaded into random access memories, RAMs, from the microprocessor prior to scanning. The RAMs allow matrix sizes up to 8×8 pixels, and as each color has its own matrix RAM it is possible to use different thresholds for different colors. During a normal scanning operation the matrices are addressed by two binary counters, one row counter and one column counter. The row counter is clocked every 0.2 mm in the scan line direction corresponding to a pixel in the image, while the column counter is clocked once for every new scanline. This creates a repetitive matrix pattern which is compared with the pixels of the continuous-tone image in the 8 bit digital comparator. The output from the comparator is the bilevel representation of the continuous-tone image in one color. As the scanner uses the three primary colors, magenta, yellow, and cyan, two more identical channels exist which are not shown in Figure 6.

When detecting the three colors in the optical scanner head as described earlier, a position error due to the arrangement of the optical fibres is introduced. This offset is corrected in digital shiftregisters located after the comparators. For simplicity these shift registers are not shown in Figure 6. The output from the shift registers is chosen so that the three color channels are always carrying information from the same image pixel before being stored in the microprocessor system. Details are described by Nilsson & Nygren (1981).

The microprocessor system

The microprocessor system mainly transfers bilevel image information from

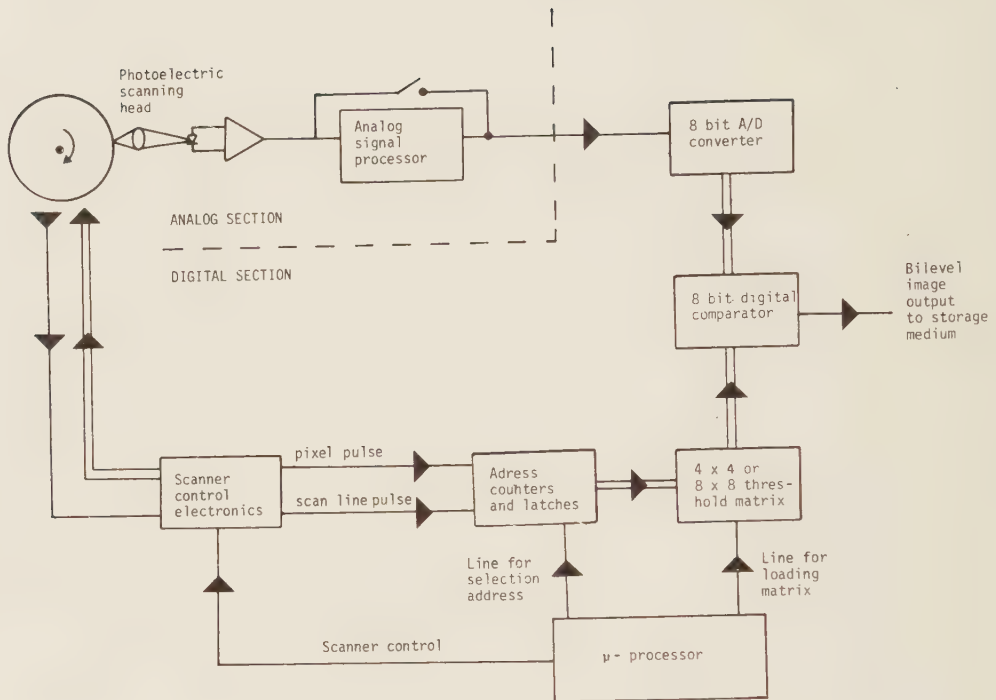


Figure 6. Functional block diagram of a bilevel scanner implemented in firmware. For clarity only one channel is shown. The analog section amplifies the input signal to suitable levels for the digital comparator section. It also allows some image processing such as gray scale expansion, compression and edge enhancement.

The digital section consists of comparator circuitry and a microprocessor system. The comparator circuitry compares the 8 bit intensity information from each continuous-tone image pixel with alternating thresholds from a threshold matrix generator.

The outcome of the comparison is only one bit for each color and pixel. Here an image compression by a factor 8:1 is achieved.

the comparator circuitry to a magnetic tape station. It also performs other tasks such as

- position control of the optical scanner head,
- magnetic tape station status control,
- operator communication over a terminal, etc.

A detailed description of the microprocessor system design is given by Nygren et al. (1982).

The transfer of bilevel image information from the comparator circuitry to the microprocessor memory is initiated by an interrupt every time 8 bits in each color are generated. When a full line, consisting of up to 432 bytes in each color, is transferred to the memory, another interrupt starts a direct memory access (DMA) transfer to the magnetic tape station where the bilevel information is stored on tape. This transfer must not slow down the normal program execution of the processor as this might result in a loss of data being transferred from the comparator circuitry into the memory. With the high transfer rates required in the present application this is not easily achieved.

Therefore, a special DMA-controller was designed, which, contrary to commercially available DMA-controllers, maintains the microprocessor's normal program execution speed during DMA-transfer (Nygren et al. 1980). In this so-called transparent DMA, the DMA controller utilizes the address and data busses when they are not required by the processor. Since this occurs at least once in every instruction cycle, the DMA-controller is working at speeds equal to or greater than the speed of commercially available controllers.

RESULTS

In this paper the flow and conversion of image-data in the color scanner have been discussed. The criteria for the selection of threshold algorithms have only been mentioned briefly, although the threshold algorithm is very important for a good bilevel image rendition of the original continuous-tone image. In Nilsson & Nygren (1981) a detailed description of threshold matrix selection and modification is given.



(a)



(b)

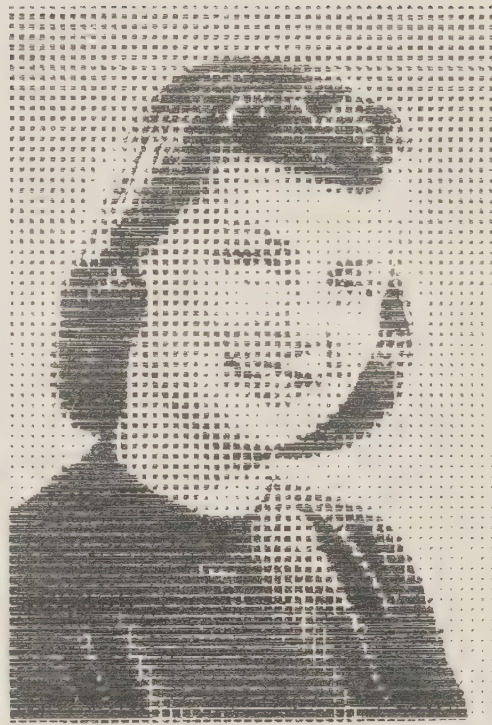
Figure 7. Reproduction using ordered dither.

(a) uses a 4×4 matrix

(b) uses an 8×8 matrix.



(a)



(b)

Figure 8. Reproduction using digital halftone

(a) uses a 4×4 matrix

(b) uses an 8×8 matrix.

As the color scanner was designed to be compatible with the color jet plotter, the modifications in the threshold matrices are due to the characteristics of the color jet plotter. The results presented here are generated on the scanner-plotter system.

In Figure 7 and 8 the reproduction of IEEE Std 167A-1980 Facsimile Test Chart Standard Girl using different threshold algorithms and threshold matrix sizes is shown. Figure 7 shows the ordered dither algorithm using a 4×4 (a) and 8×8 (b) matrix. In a 4×4 matrix 16 different threshold values are defined, which allows for 17 different gray-shades including white. This limited number of gray-shades generates the contouring effect. The contouring effect occurs in areas where the original shows slowly and continuously changing gray-shades which in the bilevel image is represented by steps, resulting in a contour around each successive step. This effect is easily visible in the background around the girl in Figure 7a.

In an 8×8 matrix 65 different gray-shades including white are possible and hence the contouring effect is less. This is demonstrated in Figure 7b. Using an 8×8 dither matrix instead of a 4×4 gives a smoother image and the same spatial resolution in high-contrast areas. The trade-off for using a larger matrix is the loss of detail in low-contrast areas. The loss of detail can barely be detected by comparing the girl's hair in Figure 7a and b.

Using the ordered dither algorithm of any matrix size a repetitive pattern in areas with a constant gray-shade cannot be avoided. This is demonstrated by the different dot patterns in e.g. the girl's face which might be objectionable at a close look.

An alternative to the ordered dither algorithm would be the digital halftone algorithm shown in Figure 8. Here the thresholds are selected to imitate the halftone method used in conventional printing. In a way this algorithm is the opposite of the ordered dither algorithm, because the thresholds are arranged so that numerically close threshold values are also spatially adjacent.

The drawback of digital halftone is the loss of spatial resolution (Bayer 1973). This can be seen by comparison of the mouth area in Figure 7a and 8a. Figure 8b shows the 8 x 8 digital halftone matrix reproduction. The reproduction's spatial resolution is very low, and unsatisfactory for most purposes.

As can be concluded from these four examples, the spatial resolution of the reproduction and the capability of generating high quality color reproductions mainly depends on the threshold algorithm used, given the hardware is not a limiting factor. We found that different applications favoured different threshold algorithms which supports our choice of a firmware solution where the threshold matrix size and content can be changed rapidly under software control.

APPLICATIONS

The scanner has been used for the generation of base maps for archeological surveys. The base map shown in Figure 9 has been generated to detect pre-historic settlements suspected in the area. Since it is known that the phosphate concentration in the ground close to such sites is heightened due to fecal matter and waste products deposited close to the dwellings, the phosphate concentration of the ground was measured at discrete points in the area. The results were fed into the host computer which interpolated the distribution of the concentration in the area as shown in Figure 9. Thanks to the base map it is easy to determine suitable sites for excavations. The result shown in Figure 9 is actually presented in color, but in this paper the different colors are exchanged for different shading patterns to accomplish an understandable output in black and white.

Other applications besides base map generation are being investigated, such as area calculation of irregular polygons and conversion of its boarder line into vector form. The list of presumptive applications is growing constantly as the need for computer color raster input devices is expanding. This expansion is due to the increasing computational power of today's computers. Their larger and faster memories, higher



Figure 9. This map shows an archeological survey where the phosphate concentration 1 meter below the surface of the ground is measured at discrete points, 2.5 meters apart. A total of over 2000 phosphate samples are interpolated over the surface in the host computer and added to the base map generated by the scanner system. Thanks to the base map it is easy to locate high concentration regions, which indicate pre-historic settlements.

CPU throughput, allow handling of large data bases which is important when working with raster input/output devices.

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